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Space-earth based Integrated Monitoring System for Water Environment

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Abstract

It is of great significance to establish a space-earth based integrated monitoring system to enhance the ability for water environmental risk prevention. Modern remote sensing technology has been used in surveying and providing urban water environment information combined with GIS spatial analysis and information management capabilities of water bodies such as lakes and reservoirs. In this paper, three monitoring methods are argued. With the use of satellite image, aerial photography and other means providing all-weather, omni-directional, multi-bands, multi-temporal remote sensing image information, the water temperature, total suspended solids, particulate matter, chlorophyll, transparency (turbidity), thermal pollution and other information could be obtained; secondly, with integrated methods of laboratory testing, water quality monitoring sites, the cross-section of the routine monitoring of benzene, phenol, COD, ammonia nitrogen, total phosphorus concentrations could be assessed; thirdly, with the use of online monitoring of toxic chemical substances, the arsenic, mercury concentration could be monitored. And the construction framework of the space-earth based integrated monitoring system for water environment was discussed. A whole scheme integrated online monitoring device, communication system, and software support system was proposed. Meanwhile, the key techniques of this system were addressed.

***Keywords**:* Space-earth based Integrated Monitoring System, Water Environment, RS monitoring , Ground routine monitoring, Ground on-line monitoring.

1. Introduction

With rapid development of global economy, the requirement of fresh water resource is greatly increasing, and more environmental pressure was put on the land waters. Shortage of fresh water, damage of water resources and water environment pollution has become a bottleneck to restrict social development, and caused also a huge environment problem, which is attracting international attentions. On one hand, as the pollutant emission has

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remained at a high level in the past decades，the accumulated water pollution problems are serious (Dasgupta et al., 2001; Shao et al., 2006). On the other hand, in the background that China enters into a high-incidence stage of environmental emergencies, taking precautions against environmental events has grave situation, the ability of emergency monitoring and management for water environment should be strengthened urgently (Wei et al., 2006).

Conventional ground-based monitoring is subject to time, space, parameters, etc.; online monitoring has realized real-time dynamic monitoring, but limited to points, cross-section monitoring; however, the remote sensing monitoring techniques with multi-scale space, multi-time scale characteristics have obvious advantages in the water environment monitoring within a regional context.

In recent years, remote sensing technology has been rapidly developed for the environment business of China. The applications of satellite imaging technology at the national survey of ecological environment, land-locked body of water bloom of red tide monitoring in coastal waters have made great achievements (Li et al., 2009; Carvalho et al., 2010). Since 1998, under the leadership of the National Disaster Reduction Committee, State Environmental Protection Administration, and National Defense Engineering Committee, China has launched its "Environment and Disaster Monitoring and Forecasting Small Satellite Constellation" successfully. With A, B Constellation launched in 2008 and environmental Satellites with ground-based monitoring network of the world, China has formed a three-dimensional integrated environmental monitoring network, which greatly enhanced the capacity of national independent environmental monitoring (Wang, 2009). So there will be a scientific research upsurge in a space-earth based integrated monitoring system of water bodies.

Under this background，applied remote sensing technology, including satellite remote sensing and environment monitoring technology based on UAV (unmanned aerial vehicle) platform, combined with conventional ground-based monitoring and on-line monitoring techniques, a space-earth based integration monitoring system could be formed to provide omni directional, dynamic environment monitoring and pre-warning of the water bodies and regional eco-environment. And this will be of great significance both practically and theoretically to enhance the ability for environmental risk prevention and emergency response.

2. Overview of Space-earth based Integrated Monitoring System

2.1. Framework of the system

On the base of a space-earth integration monitoring net, combined with ground and RS data, water quality of water bodies could be monitored through a series of parametric inversion and data fusion technologies. Firstly, with the use of satellite imaging, aerial photography and other means providing all-weather, omni-directional, multi-bands, multi-temporal remote sensing image information, the water temperature, total suspended solids, particulate matter, chlorophyll, transparency (turbidity), thermal pollution and other information could be obtained; secondly, with integration methods of laboratory testing, the water quality monitoring sites, cross-section of the routine monitoring of benzene, phenol, COD, ammonia nitrogen, and total phosphorus concentrations could be assessed; thirdly, with the use of online monitoring of toxic chemical substances, the arsenic, mercury concentration could be monitored.

The establishment of a space-earth based integrated monitoring system of water bodies (Figure 1) is the most efficient way to promote means of using three types of monitoring data and analysis capabilities for water environment management of water bodies.

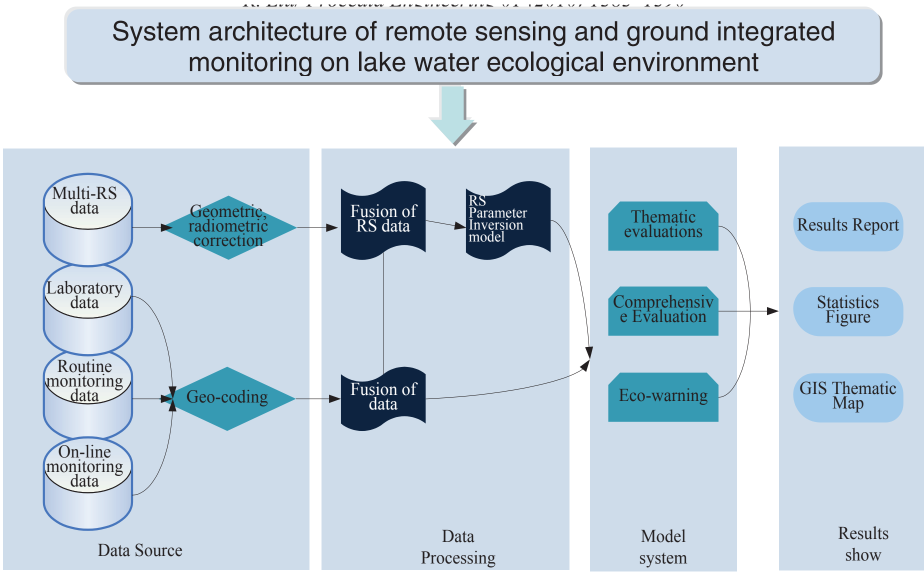

Fig. 1. System architecture of remote sensing and ground integrated monitoring on lake water ecological environment

2.2 Monitoring Network Architecture

The structure of water environmental monitoring network based on space-earth integration observation was shown in Fig. 2. This network system includes three parts, i.e., monitoring system, commanding platforms and communication system. The monitoring system consists of environmental satellites, environmental emergency UAV, environmental emergency monitoring vehicle, environmental emergency monitoring boat, water quality on-line monitoring equipments and portable environmental emergency monitoring devices. And the commanding platforms comprise scene command platform, small-scale mobile emergency platform and the environmental emergency command center in the Environmental Protection Bureaus.

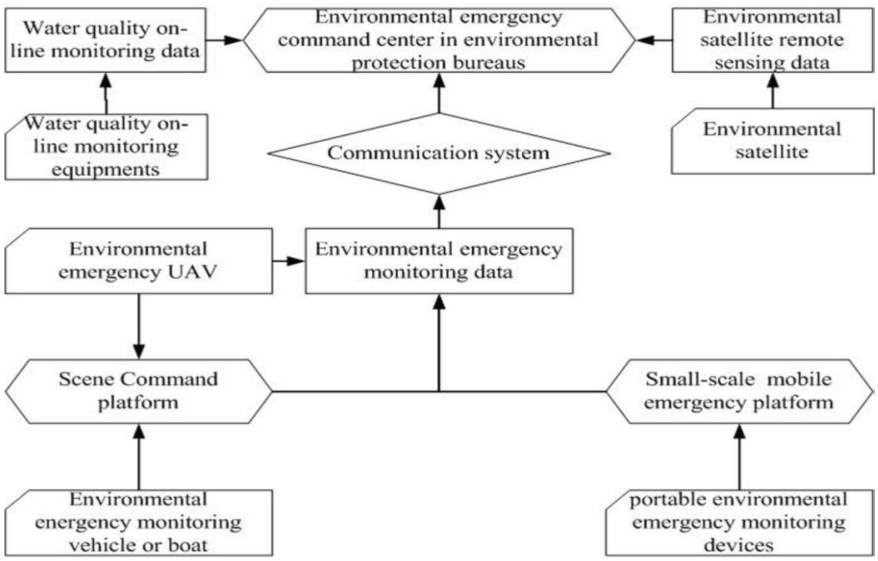

Fig.2. Structure of water environmental monitoring network based on space-earth integration system

2.2.1 RS monitoring of water quality

Remote sensing for water quality is a method that can be applied to ground, aviation and aerospace remote sensing platform to detect river, lake, reservoir and sea, and measure their reflection, emission and absorption features, and then determine the distribution and site of water pollution quickly. Infrared scanner, multispectral scanner, microwave system and lidar are the common instruments of water quality remote sensing whose monitoring objects mainly are oil pollution on the water surface, water suspended substance, sewage discharge, type and density of Red Tide, etc.

The factors of water body water quality remote sensing include water temperature, total suspended solid particulate matter, chlorophyll, transparency (turbidity), thermal pollution, and other information (Schiebe et al.,1992; Dekker and Peters, 1993; Fraser, 1998; Giardino et al., 2001; Kloiber et al., 2000; Giardinoa et al., 2007; Li et al., 2009). These water quality parameters in remote sensing images need remote sensing data inversion model for pre-processing, extracting the intuitively thresholds to reflect the lake water quality.

Quantitative remote sensing of water quality requires that researchers have a good grasp of water components' spectral characteristics. Water data can be collected on the ground to exclude the impact of the atmosphere with spectrum measuring instrument. Hyperspectral remote sensing data of water with narrow band can be obtained to reflect a slight change in spectral features (Li et al., 2009).

Multi-spectral remote sensing is superior to single-band or panchromatic remote sensing, because more information could be provided to help identify a number of similar objects. Therefore, the quantitative of water quality remote sensing inversion needs to select sensitive bands firstly and then analyze bands most closely related to a variety of water quality indicators with high spectral. However, there is a correlation between different bands in multi-spectral remote sensing data, which reduces the amount of information that theoretically could provide. As the relevance in multi-spectral remote sensing data relating to the remote sensing system design, it is necessary to study the correlation of multi-spectral remote sensing data deeply. The research on quantitative inversion model of water quality remote sensing can find water quality indicators' most sensitive bands, application of TM, SPOT, MODIS, MERIS, AVHRR, CASI sensors, as well as the causes and the solutions to errors of water quality remote sensing model (Tong et al., 2007). Based on the research results, the remote sensing system performance can be improved according to this correlation.

In addition, a growing number of researchers have used different types of spectrometer, combined with different measurement methods to obtain the spectral data of water body in the field or the laboratory. The characteristic information of water body components is extracted through the correction of spectral data. Thereby the apparent optical volume and the amount of inherent optical water could be solved. The interaction between water components and spectra can be considered as a very complex non-linear relationship. It combines with mathematical statistical methods to build empirical analysis, semi-empirical analysis or semi-artificial neural network black-box model to simulate, explore apparent optical properties and inherent optical properties, as well as their quantitative inverse relation in different water bodies or the same body of water in different time frames. A quantitative inversion model could be used to inverse the main effective factors to optical properties of water, such as chlorophyll a, yellow CDOM and concentration of suspended particulate components.

Quantitative remote sensing inversion of water quality is bound to be combined with water ecological problems, since it attempts to practical use ultimately, as a monitoring tool. It will be widely applied in spatial and temporal distribution of water algae, watershed nutrient transport model and the lake water quality model. More precise monitoring results obtained by hyperspectral data source is still relatively lack, due to the wide band of China's satellite, which was used to monitor water quality. More bands suitable for water quality remote sensing should be joined to the new generation of resources and the environment satellites (Zhang et al., 2007).

2.2.2 Ground routine monitoring

Ground routine monitoring is a conventional method including laboratory testing, water quality monitoring sites and cross-section. This method is mainly to obtain benzene, phenol, COD, ammonia nitrogen, total phosphorus concentration of such indicators. The optical characteristics of these water quality parameters weren't reflected obviously in water quality remote sensing images spectrum, or it is not easy to obtain more accurate and reliable information by water quality remote sensing reversion model, while it's easy by the ground laboratory testing. Thereby, conventional monitoring methods are still used as auxiliary methods to attain water quality parameters.

The monitoring results, as part of ecological environment indicators of lake, are included in the index system to participate in a comprehensive assessment of the ecological environment.

2.2.3 Ground on-line monitoring

Ground on-line monitoring can be a real-time monitoring and pre-warning system. It transmits the monitoring pollution data by installing on-line monitoring equipment and data acquisition equipment to pollution sources. The main target of this method is the water quality parameters of the enterprise sewage outfall. Now some water-line automatic monitoring system products which monitor the specific water quality parameters also have been developed. The permanganate index, total organic carbon (TOC), BOD_5, ammonia nitrogen, total nitrogen, total phosphorus, nitrate, nitrite, phosphate salt, sulfur, arsenic, heavy metals (copper, lead, zinc, cadmium, chromium, etc.), cyanide, phenol, fluoride, oils, toxicity, VOC and other water quality factors could be monitored. As an essential environmental contingency method, ground on-line monitoring plays an important role in space-earth based integrated monitoring system of water bodies.

The routine and on-line monitoring on the ground is still only a point or section monitoring, since lakes are water body, the matter and energy circulation process of water is also different in different regions. More comprehensive data and information is needed to simulate water pollution process of water bodies and analyze the successive evolution law of the water ecological environment.

It is the most effective use of the information by combining the above three types of data.

2.3 Data fusion and water environment assessment

Fusion of different platforms and periods of conventional optical RS, hyperspectral RS and radar RS data and measured data, combination of geography-based coding "3S" technology, water quality remote sensing inversion quantitative model, digital-analog methods, and field observations experiment, can be carried out to monitor the water environment of water bodies and assess the impact of the pollutions. The proliferation and migration laws of chlorophyll, suspended solids, organic matter and other major indicators of water quality could be analyzed, and the monitoring methods of water ecological and assessment systems of environmental impact could be established.

A geographic information system platform could be built to collect, manage, query, analyze, operate and perform geographic-related information, and provide important support platform for analysis and decision-making.

Supported by the underlying database, comprehensive evaluation, thematic evaluations (water eutrophication, plant diseases and pests, etc.) as well as the ecological warning about lake water ecosystems can be achieved through data processing and model analysis of professional RS and GIS software. Finally, the analysis of water environment is displayed by the reports, thematic maps on the GIS platform.

3. Key technologies

3.1 Satellite Remote Sensing Monitoring

Multisource satellite remote sensing monitoring (MSRSM) possesses exceptive superiorities on environmental use, such as wide coverage, low cost and adapted for long-term dynamic monitoring. Its application in environment area has become increasingly extensive, along with the mature of multisource remote sensing technology for the future research. With conventional terrestrial monitoring and online monitoring technology, applying the MSRSM technology into environmental emergency monitoring, thereby a space-earth integrated stereo monitoring system could be generated for all-directional, dynamic monitoring and early warning function in water environment area, moreover in providing information services.

As to the part of water environment remote sensing, according to mechanism differences, water environment remote sensing could be divided into two sectors, i.e., ocean color remote sensing and inland water remote sensing(Gordona and Franz, 2008). For the present, China has started business application and operation in ocean color remote sensing sector, the main monitoring index include ocean water temperature, chlorophyll a, suspended material, sea ice and etc; the main operation satellites include FY1C and FY1D from ‘Fengyun’satellite series, HY-

1A and HY-1B from ‘Ocean’ satellite series. Influenced by hyper space-time resolution and hyperspectral resolution restriction, China now mainly is using satellite data from European and American developed countries, such as Environment Satellite No.1 (HJ-1), China-Brazil Environment Resources Satellite (CBERS), and to operate inverse transformation for inland water body index, but the results were not good on the whole.

Although China has accomplished the first step in environment monitoring, it still needs to face plenty of the challenges and problems. China doesn't have specified environment monitoring equipment for satellite remote sensing. As the particular purpose, Satellites A and B from Environment No.1 Constellation are far lack of effectiveness load of spatial resolution, time resolution, spectral resolution. The spectral range are inconsequence, although they are carrying wide coverage multispectral charge-coupled device (CCD), infrared camera, hyperspectral imager and other effectiveness equipments, while China are lack of specified satellite load for environment monitoring. On the other hand, the active demand of environment monitoring index for emergency can not be detected (e.g. COD, BOD, total phosphorus, total nitrogen and etc. in water environment), and all-weather, all-day environment monitoring can not be achieved. Lack of High-resolution satellite data, micro-satellite data based on rational remote sensing inversion technique and environment incident tracking-monitoring technology research in water environment field, has now become the structural factor to restricting China's environment monitoring and satellite business operational applications (Wang et al. 2009).

3.2 Water environment monitoring technology based on UAV platform

The unmanned aerial vehicle（UAV）is characterized by the flexibility of rising & falling way and transportation way, wide monitoring rang and long-lasting monitoring time, which accordingly could overcome the shortage of environment emergency monitoring vehicles and ships. Its capability of taking aerial photography and video has had a wide application. Although Environment Emergency UAV is a key part of environment emergency monitoring network of “Space-earth Integration”, and some progresses have been made on the air pollutant concentration test experiment based on UAV platform in our country (Gao et al., 2010), however, due to the lack of successful experience, water environment emergency monitoring technology based on UAV platform is still at the exploration stage.

3.3 Insurance of Communication System

The main tasks for capability construction of emergency management are the guarantee of the emergency communication. At present, a multi-model, high-coverage environment emergency communication system has not been set up yet in our country. Satellite movement communication is an efficient approach which can take full advantage of its flexibility and coverage and dealing with the emergent communication problems, thus playing an unchangeable role in disaster prevention and reduction. Therefore, multi-purpose and large volume communication satellite should be vigorously developed, and the satellite communication system of our country, which is composed of satellite fixed-line communication, satellite movement communication and broadband communication, should be constructed as well. In addition, wireless adhoc network (WAN) communication technology has not been taken enough attention in the environment emergency system construction in our country. Once this WAN technology is applied into the environment emergency monitoring to realize convenient and rapid temporary adhoc network and data transportation, the guarantee capability of emergency communication will be further enhanced.

3.4 Environment Simulation

Correct simulation and forecast for accidental environment events is the sound basis of environment emergency decision-making. So far there is still not a unified standard on environment emergency simulation technique in our country, and we still have a big distance from foreign countries on related model technique research in reality. So we should strengthen the simulation research on emergency response pollutant spreading, such as the data simulation research on developing multi-scale water pollution, and high-rank inversion study on source strength with the real-time measured concentration, etc.

4. Conclusion

The traditional monitoring of lakes and such water bodies is mainly a point monitoring. It’s hard to reflect the space change of water environment and attaint an objective analysis. The rapid and objective space monitoring of RS overcomes the deficiencies of traditional methods, in providing a scientific solution for surface water quality monitoring. A large number of simultaneous observation experiments about remote sensing satellites transit and simulation experiments about hydrology, water environment, coupled with the migration characteristics and laws of apparent optical properties/ inherent optical characteristics of water bodies and chlorophyll, suspended solids, organic pollutants, integrated with different platforms of conventional optical remote sensing, hyperspectral remote sensing and radar remote sensing and other multi-source data, could be applied to study the monitoring techniques of lakes quality, and establish the remote sensing inversion model of lakes water quality, so that remote sensing inversion, monitoring and evaluation of lake environment in different periods could be achieved.

The establishment of space-earth based integrated monitoring system of water bodies is the most efficient way to promote means of using three types of monitoring data and analysis capabilities for water environment management of water bodies, so as to provide an effective basis for information management and decision-making. But this system should be improved from the following four aspects: (1) satellite remote sensing monitoring for environmental quality, (2) environmental emergency monitoring based on unmanned aerial vehicle, (3) protection of communication security system, (4) integration of GIS and computational models for environmental emergency management. This system will play an important role on environmental emergency response.

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